Comparison of the Physics of Wideband/Off-Axis Beams

Patrick Huber

University of Wisconsin – Madison

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Outline

- Why off-axis?
- Why wide band?
- NOνA with two detectors
- Wide band beam with one detector
- Comparison
- Summary & Conclusion

Why off-axis?

The off-axis technology is appealing because

- simple tuning of beam energy
- narrow beam – concentrates the events around the oscillation maximum and allows to do a “counting” experiment
- no high energy tail – high energy neutrinos produce lots of NC events which tend to be reconstructed at low energies
- low background – somewhat reduced ν_e contamination

Why not off-axis?

The off-axis technology has intrinsic limitations

- narrow beam – concentrates the events around the oscillation maximum and reduces to do a “counting” experiment
- background – ν_e contamination

Being a counting experiment implies that absolute event numbers are important, thus it is very demanding in terms of systematics. It also means that one can measure only two numbers n_ν and $n_{\bar{\nu}}$. Virtually impossible to resolve the degeneracies.

Why off-axis?

The solution to the 'only two numbers' problem is to put a second detector at a different location.
A different location either means a different off-axis angle hence a different energy or a different baseline. This can result in a different L/E and thus allows to move into the second oscillation maximum. Where the CP and matter effects are very different.
Or one choose a location with the same L/E but a very different L and thus a very different magnitude of matter effects.

see Olga's talk

Why wide band?

One may consider a wide band beam because

- higher energy (not always an advantage) – longer baseline, more matter effects
- higher on-axis flux
- broad spectrum – many values of L/E at the same time
- energy information to fight systematics

Why not wide band?

Wide band beams also have some drawbacks

- high energy – long baseline for the first maximum reduces flux
- high energy tail – NC feed down, puts stringent demands on the detector
- broad spectrum only useful if the energy resolution is sufficient

This puts the emphasis on the detector side: large mass to compensate distance, good energy resolution and NC rejection

What do we learn from that?

Just on general grounds, it is not possible to say which approach works better. To tackle that question a full simulation is required, since the answer depends on many details: energy resolution, NC background, beam power, available baselines, detector technology, money ...

In the remainder of this talk I try to take what was available to me to approach that goal – I didn't get too close, though.

Some of the following results are very preliminary!

Analysis

Oscillation parameters and errors:

$$\Delta m^2_{21} = 8 \times 10^{-5}\,\mathrm{eV}^2 \pm 10\% \quad \theta_{12} = 0.55 \pm 10\%$$

$$\Delta m^2_{31} = 2.5 \times 10^{-3}\,\mathrm{eV}^2 \pm 10\% \quad \theta 23 = \pi/4 \pm 10\%$$

Full oscillation analysis including disappearance channels, energy information, systematics, matter density error of 5% with GLoBES.

The three questions

We want to learn three things from an advanced neutrino experiment

- $\theta_{13} \neq 0$ – if it shouldn't have been found
- $\mathrm{sgn}\Delta m^2_{31}$ – so called mass hierarchy
- δ – is CP violated in the lepton sector?

Therefore I will use these indicators

- θ_{13} discovery potential – exclusion of $\theta_{13} = 0$
- $\mathrm{sgn}\Delta m^2_{31}$-discovery for normal hierarchy – assuming $\Delta m^2_{31} > 0$ exclusion of $\Delta m^2_{31} < 0$
- CP violation – exclusion of CP conserving values $\delta = 0$ and (!) π

Acknowledgments

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NOνA + 2nd detector

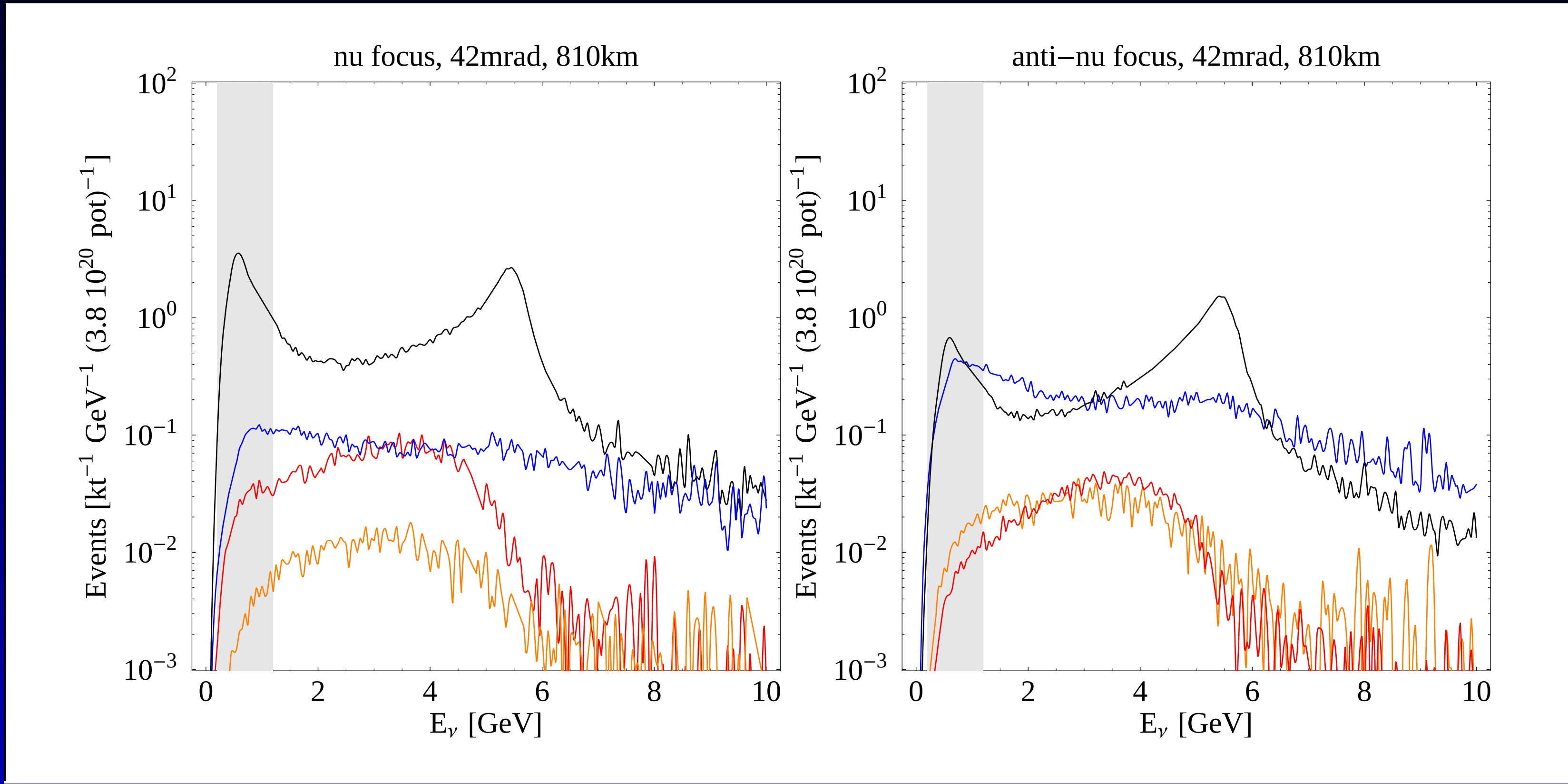
There have been two different ideas on the (US) market:

- 2nd detector at $710\,\mathrm{km}$ and $30\,\mathrm{km}$ off-axis $(42\,\mathrm{mrad})$ – second oscillation maximum
  NOνA proposal, 2005
- 2nd detector at $200\,\mathrm{km}$ and $8.4\,\mathrm{km}$ off-axis $(42\,\mathrm{mrad})$ – first oscillation maximum
  O. Mena Requejo, S. Palomares-Ruiz and S. Pascoli 2005

In both cases a $50\,\mathrm{kt}$ water Cherenkov detector á la T2K is among the considered options.

Both scenarios assume a FNAL proton driver and 6 years ν and 6 years $\bar{\nu}$ with NOνA and 3 years ν and 3 years $\bar{\nu}$ for the 2nd detector.

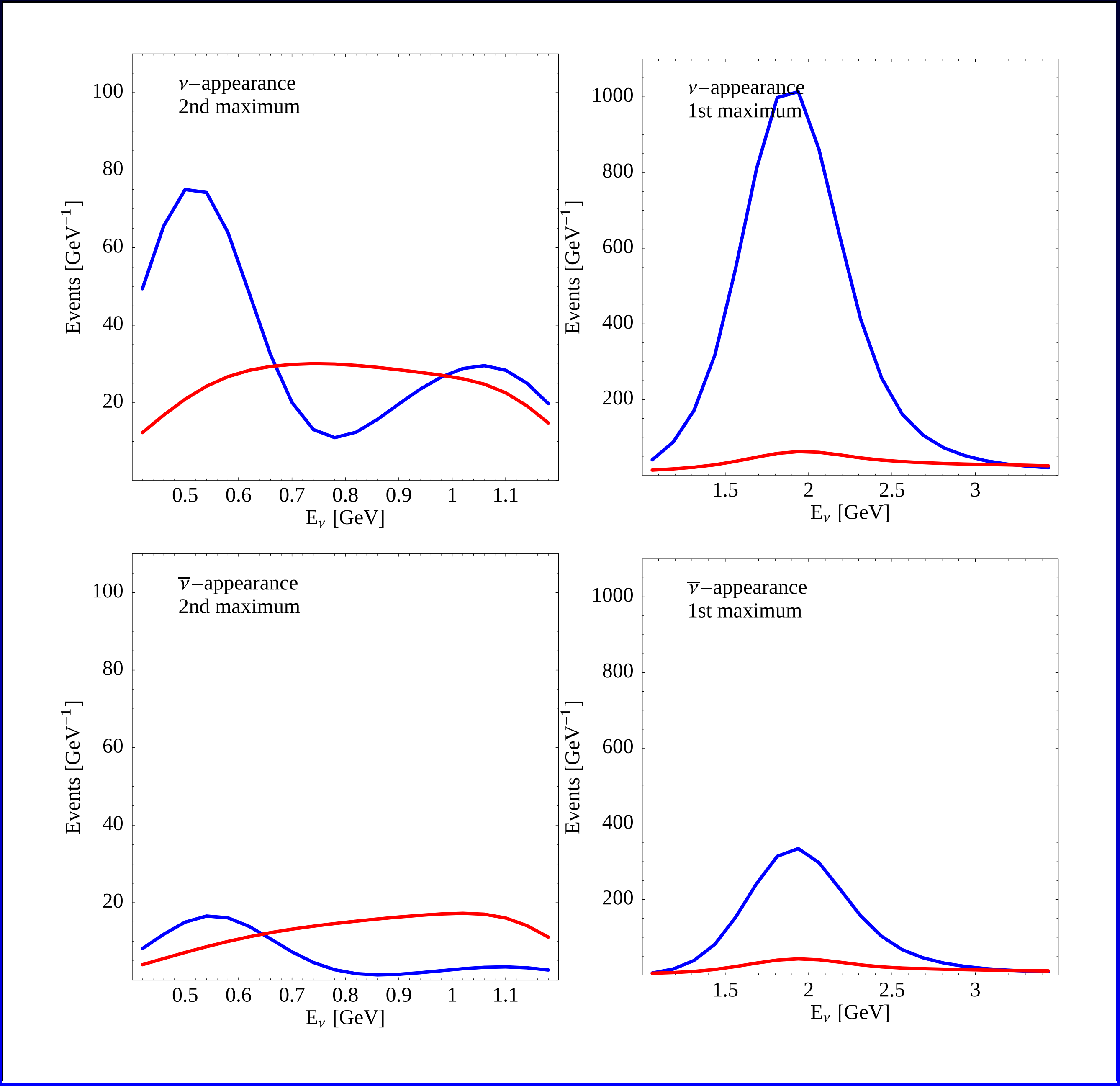
Beam at 42mrad



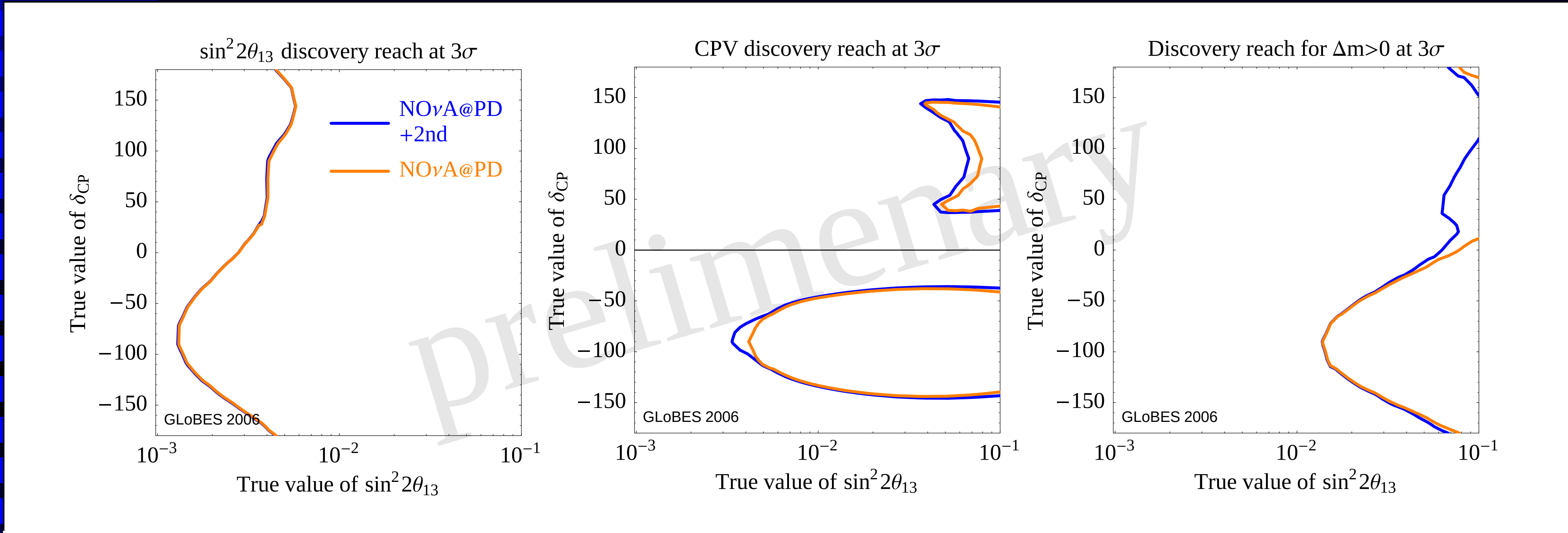
- What happens with the second peak?
- ν background to $\bar{\nu}$ signal very large
- Only gray shaded region considered here

see B. Flemming's talk

Rates @ $\sin^2 2\theta_{13} = 0.1$



NOνA + **2nd detector**



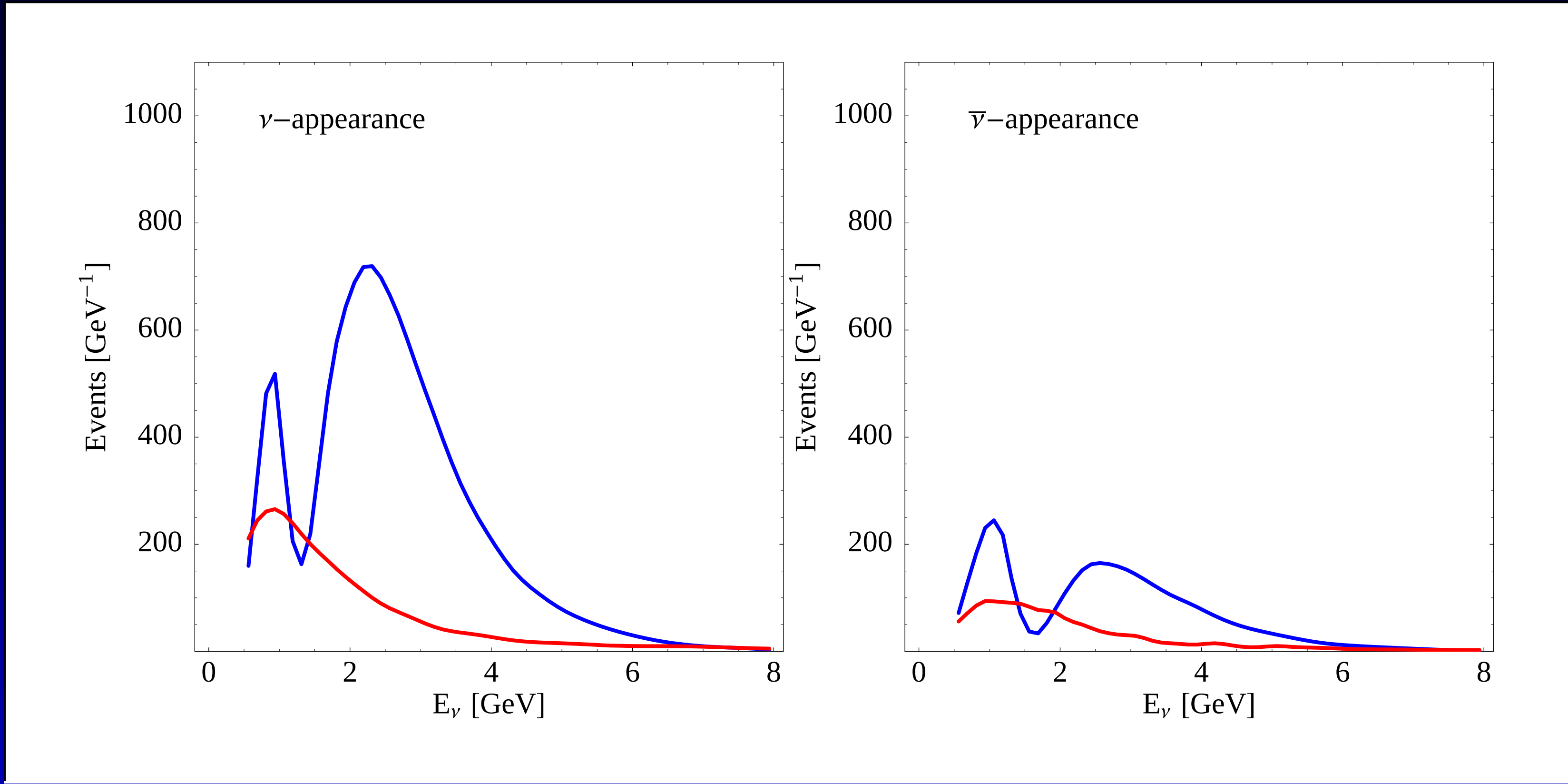
- problems due to π-transit for $\sin\delta > 0$
- water Cherenkov is not optimal
- Super-NOνA performs similar

Wide band beam

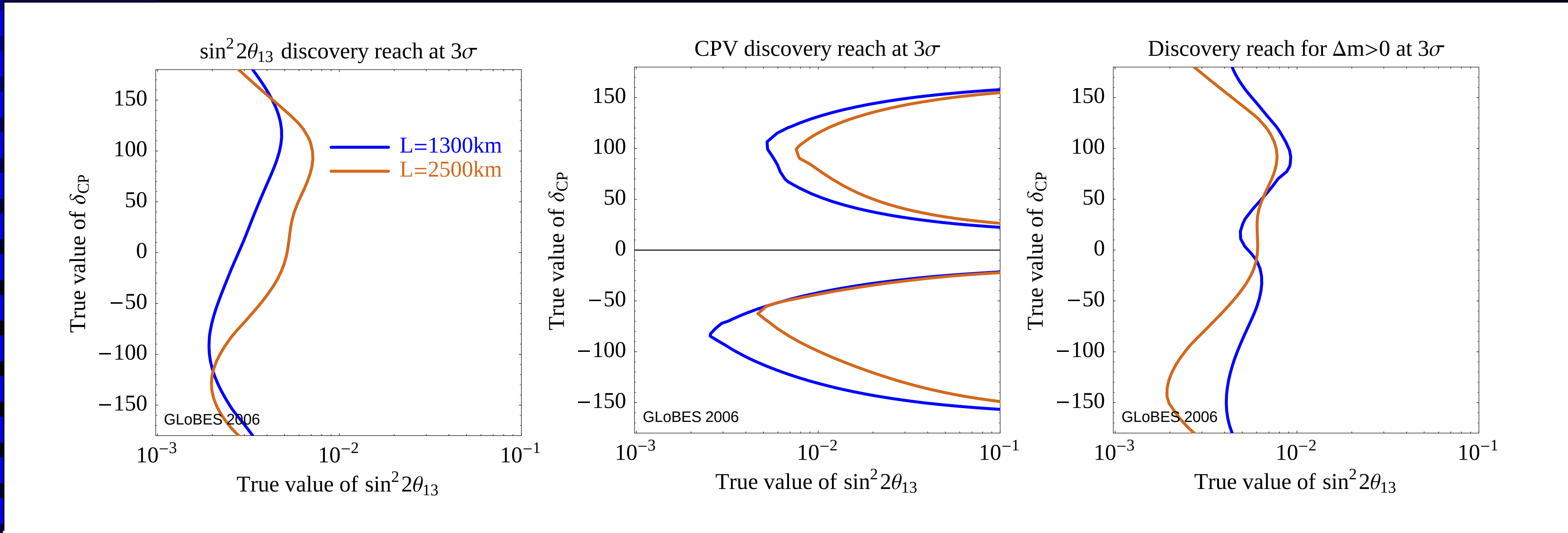
- protons with $E = 28\,\mathrm{GeV}$ and $P = 1\,\mathrm{MW}$
- $500\,\mathrm{kt}$ water Cherenkov detector
- π^0 suppression verified by Super-K MC
  see Yanagisawa's talk
- $5 \times 10^7\mathrm{s}$ neutrino running
- $5 \times 10^7\mathrm{s}$ anti-neutrino running
- 10% uncertainty on the background
- $L = 1300\,\mathrm{km}$ or $L = 2500\,\mathrm{km}$

With the FNAL proton driver this corresponds to 12 years with a $100\,\mathrm{kt}$ detector $\longrightarrow$ same run time as NOνA +2nd detector

Rates @ $\sin^2 2\theta_{13} = 0.1$

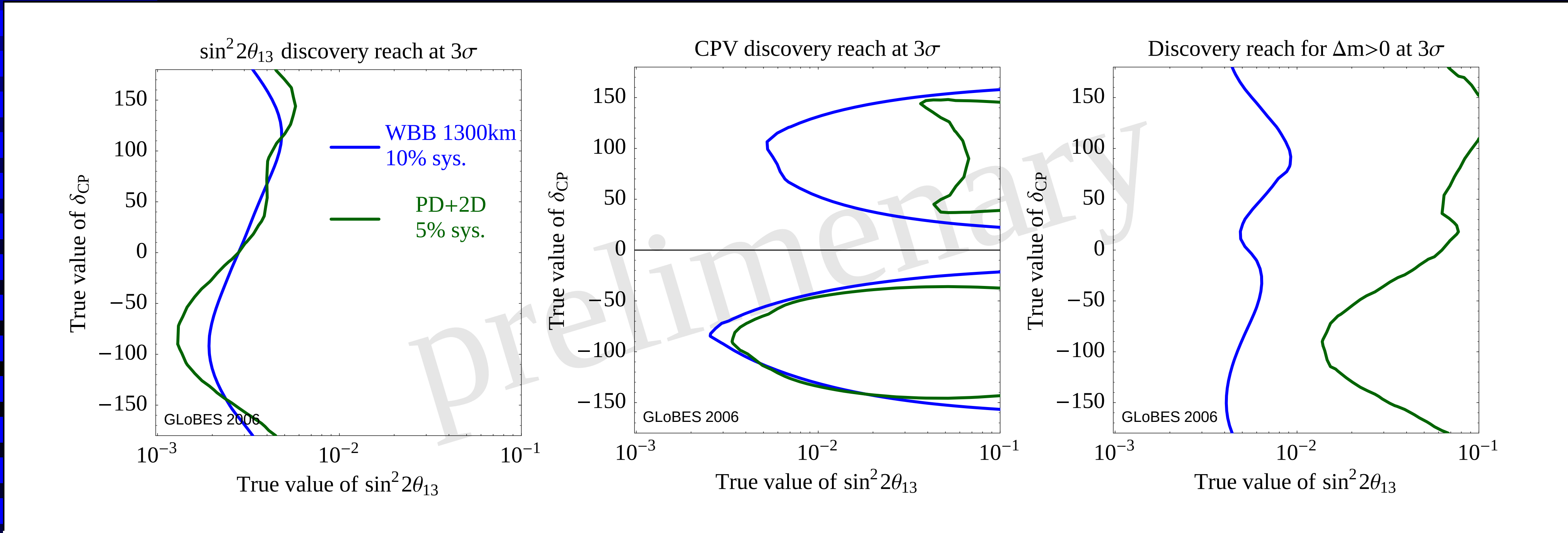


Wide band beam



- very good resolution of the mass hierarchy
- no problems due to π-transit for $\sin\delta > 0$
- Baseline choice is not critical

Summary



How would that picture look like with

- Liquid Argon
- 2nd peak in the OA spectrum

Open issues

- Detector performance is crucial $\Rightarrow$ need quantitative understanding of the different technologies
- Systematics are important, esp. for OA beams
- How does the US effort compare to e.g. Japan
- ...